Monte-Carlo Maneuver Analysis for the Microwave Anisotropy Probe

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Introduction

The Microwave Anisotropy Probe (MAP) spacecraft is part of NASA's Explorers Program. It will orbit about the Sun-Earth L2 Lagrange point. To reach this halo orbit, a series of phasing loops achieve the necessary lunar gravity assist. The first launch opportunity is in June 2001. Depending upon the launch date, three or five phasing loops may be used. In either case, the navigation plan includes correction maneuvers at apogees and perigees of phasing loops, plus a pre-Lunary-swingby correction maneuver about 18 hours after the last perigee to ensure both an accurate lunar swingby and one that will lead to an lissajous orbit that meets mission constraints.

These maneuvers are the subject of the Monte-Carlo analysis herein. The software program LAMBIC was used to perform the maneuver simulation and estimate the fuel margin, accounting for modeling of injection, orbit determination, and maneuver execution errors. LAMBIC uses linearization to both simplify the problem and speed-up execution. As a result, particular attention is paid to the linear range of the trajectory's maneuvers. Also, important differences between MAP project plans and the maneuver modeling capabilities of LAMBIC are discussed. It is important to understand such differences as they apply to this mission and possibly to future phasing-loop/halo-orbit missions.

Assumptions

For injection errors, both a full covariance matrix and a simple injection error model were used. The injection ΔV execution error model consisted of a magnitude error of 11.6 m/s and a pointing error of 2 degrees, at the three-sigma level for both.

Maneuver execution errors for P1, Pf, and PfCM were specified as 5% magnitude and 5 degrees pointing at the three-sigma level. Orbit Determination (OD) uncertainties were specified as 300 meters and 10 mm/s at the three-sigma level. These OD uncertainties apply to the data cut-off time for maneuver design.

In to generate files necessary to LAMBIC, the MAP trajectory had to be reproduced with the DPTRAJ software set. This was done with the intent of matching the models used by the MAP team: a 21-by-21 JGM-2 for Earth; all gravitational influences but Earth, Moon, Sun, and Jupiter were neglected; and solar radiation pressure was modeled. From this trajectory, partial derivatives were save to a file upon which LAMBIC bases it's linear models.

Maneuver Simulation Results

The LAMBIC software offers many options for simulating maneuvers. The strategy chosen as the closest match to MAP's was the following: always target the final perigee maneuver (Pf) to the nominal lunar swingby B-plane target, ignoring time of closest-approach, but choose the earlier maneuvers such that the ΔV total is a minimum. Target the clean-up to Pf (PfCM) in the same manner as Pf.

The simulations include 5,000 samples. In addition to mean values, LAMBIC can produce ΔV tabulations at any given percentile level; for the Nth percentile level, there is an N% chance that the actual ΔV magnitude will be smaller. In order to clearly show how the individual models affect the estimate of required ΔV, a progression of solutions is presented, beginning with maneuvers that compensate for only the injection error. This is followed by results accounting for injection errors and orbit determination (OD) errors at each maneuver, next by injection errors and only maneuver execution errors, and finally by all three types of errors. Results for the May 4th launch date are shown below.

Table I: LAMBIC Results for May 4th Launch. Results are given in m/s. Mean ΔV is listed as μ, standard deviation (1-sigma) as σ, and the 99th percentile level is listed under 99%.

MVR	Injection			Injection + OD Error			Injection + Execution Error			Injection + Execution Error + OD Error		
	μ	σ	99%	μ	σ	99%	μ	σ	99%	μ	σ	99%
P1	15.6	5.38	28.2	15.6	5.38	28.3	15.6	5.39	28.3	15.6	5.39	28.3
Pf	13.0	1.11	15.4	13.2	1.14	15.6	16.9	5.27	36.7	17.1	5.39	37.8
Pf CM	0.0	0.0	0.0	0.51	0.29	1.37	1.87	1.80	8.82	2.03	1.81	9.00
Total	28.5	4.93	40.2	29.3	4.97	41.2	34.4	9.48	65.3	34.7	9.56	67.2

Concluding Remarks

These estimates presented here are subject to several caveats, most notably the reliance on linear approximation. Also, the Pf and PfCM maneuver targets were taken to be the nominal lunar-swingby aimpoint. The resulting estimates of required ΔV are subject to the assumption that achieving this aimpoint is a good approximation to the MAP maneuver strategy. Further investigation of this assumption is needed. This analysis makes no attempt to estimate the ΔV required for any maneuvers after the lunar swingby.